

# Evidences for an expanding shell in the Blue Compact Dwarf Galaxy Haro 2

F. Legrand<sup>1</sup>, D. Kunth<sup>1</sup>, J.M. Mas-Hesse<sup>2</sup> and J. Lequeux<sup>3</sup>

<sup>1</sup> Institut d'Astrophysique de Paris, CNRS, 98bis boulevard Arago, F-75014 Paris, France.

<sup>2</sup> LAEFF-INTA, Apdo 50727, E-28080 Madrid, Spain.

<sup>3</sup> Observatoire de Paris, DEMIRM , 77, Av. Denfert Rochereau, F-75014 Paris, France.

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**Abstract.** Long-slit observations of the blue compact galaxy Haro 2 have been performed around H $\alpha$  and H $\beta$ . The main aim of these observations was to detect the H $\alpha$  emission originating in the partially ionized wind outflowing at 200 km/s, that had been previously detected with the Hubble Space Telescope (HST). A shallow broadening of the H $\alpha$  line wings has been observed, consistent with the existence of an expanding shell. The rotation curve shows two dips at the same systemic velocity as the nucleus. We interpret this feature as an evidence that the expanding shell is decoupled from the disk rotation. At the positions of the dips the H $\alpha$  line is clearly broadened with respect to the central core. This broadening is produced by the outer layers of the expanding shell. From the position of these dips we estimate the size of the shell to be around 20" in diameter, with a corresponding kinematical age between 5 and 6 Myr. This shell has most certainly been powered by the massive star formation process that takes place in the central region of this galaxy. A comparison of the H $\alpha$  and Ly $\alpha$  profiles shows that Ly $\alpha$  is significantly broader than H $\alpha$ , with an additional emission in the red wing. We interpret this redshifted source of Ly $\alpha$  emission as line photons backscattered by the receding part of the expanding shell. These observations outline the extremely high sensitivity of the Ly $\alpha$  line to the structure and kinematics of the interstellar medium (ISM). Finally the analysis of stellar Balmer lines in the H $\beta$  region indicates that stars less massive than 10 M $\odot$  have probably been formed.

**Key words:** Galaxies: ISM – Galaxies: starburst – Galaxies: kinematics and dynamics – Galaxies: individual: Haro 2

Send offprint requests to: F. Legrand

## 1. Introduction

Theoretical studies of primeval galaxies (Partridge & Peebles 1967, Meier 1976) have suggested that they could initially experience a strong massive star formation episode, and should therefore exhibit strong Ly $\alpha$  emission. If so this line would be an ideal tracer of primeval galaxies at high redshifts. Since Blue Compact Dwarf Galaxies (BCD) experience also strong star formation events, they could be regarded as local counterparts of the primeval galaxies, hence constituting an excellent laboratory to study the relation between star formation and Ly $\alpha$  emission (Meier & Terlevich 1981, Hartmann et al. 1988). The first observational results in studying Ly $\alpha$  emission in HII galaxies were nevertheless surprising, since the Ly $\alpha$  emission came out much fainter than expected in some starburst galaxies, while no emission at all could be detected in others.

The problem of Ly $\alpha$  emission in galaxies experiencing starburst episodes has been studied by numerous authors through the last years (Neufeld 1991, Charlot & Fall 1991, Terlevich et al. 1993, Calzetti et al. 1994, Kunth et al. 1996, Giavalisco et al. 1996) and its interpretation has evolved with time. The first IUE (International Ultraviolet Explorer) studies suggested a correlation between the presence of Ly $\alpha$  emission and metallicity, hence dust alone was first pointed out as the principal cause for the reduction of Ly $\alpha$  emission. New results from HST (Kunth et al. 1994) have shown that galaxies with very low metallicity, as IZw18, can have no Ly $\alpha$  emission while some galaxies with more metals, like Haro 2 (Lequeux et al. 1995), exhibit Ly $\alpha$  emission. On the other hand the spectral resolving power of the Goddard High Resolution Spectrograph onboard HST made possible to detect P Cygni profiles in the Ly $\alpha$  line of several starburst galaxies (Kunth et al. 1996). This suggests that the detectability of the line is strongly affected by the geometrical and kinematical properties of the interstellar medium. In BCD's, massive stars are numerous and power strong stellar winds that have a significant impact into the surrounding interstellar

medium. Recent observations (Marlowe et al. 1995, Martin 1996, Izotov et al. 1996, Yang et al. 1996) have revealed the presence of winds, shells and bubbles expanding at high velocities in a number of starburst galaxies. These objects are therefore well suited to investigate the link between the Ly $\alpha$  emission and the properties of the ISM.

In this context, HST observations of a sample of emission-line galaxies (Kunth et al. 1996) around Ly $\alpha$  and OI 1302 Å have been performed. Among them Haro 2 appears to be a relatively metal-rich blue compact galaxy with a metallicity around  $\frac{1}{3}$  solar (at least 10 times more than IZw 18). Its recession velocity is 1465 km/s (Lequeux et al. 1995) and its absolute magnitude, assuming  $H=70$  km/s/Mpc is  $M_B = -18.7$  (Kunth & Joubert 1985). The apparent extinction in this galaxy varies from  $E(B-V)=0.12$  from the far-UV (Mas-Hesse & Kunth 1997, in prep.) to  $E(B-V)=0.7$  from the Balmer decrement (Davidge 1989) and  $E(B-V)=1.4$  using the H $\beta$  over Brackett  $\gamma$  ratio (Davidge & Maillard 1990). This discrepancy between the extinctions measured at different wavelengths is a frequent property of extragalactic HII regions which is attributed to inhomogeneities in the foreground absorbing screen (Lequeux et al. 1981). At short wavelengths, radiation emerges preferentially through places with low extinction; consequently the extinction measured at these wavelengths appears smaller than the average extinction which is better measured at longer wavelengths. Lequeux et al. (1995) observations have shown that the Ly $\alpha$  emission is clearly asymmetric, with a clear P Cyg profile revealing the existence of a partially ionized gas, outflowing at 200 km/s from the main central HII region. The interpretation suggested by Lequeux et al. (1995) is that a neutral expanding medium is responsible for the Ly $\alpha$  absorption. Since absorption features due to OI 1302 Å and SiII 1304 Å seem to be centered at the velocity of the outflowing partially ionized gas (200 km/s), the neutral expanding medium should be at this velocity, pushed by the ionized expanding medium and absorbing the blue part of the Ly $\alpha$  emission line. Moreover, the red wing of the observed Ly $\alpha$  emission is broad suggesting the presence of an additional source of photons which could be due to the emission of the receding ionized medium or to backscattering of Ly $\alpha$  photons on the receding neutral gas.

The objective of this work is the analysis of the Haro 2 H $\alpha$  emission line profile in order to detect the broad component potentially emitted by this ionized expanding medium, and to compare this profile with that of Ly $\alpha$ . Since these two lines are produced by the same physical process, hence essentially in the same regions, the differences in their profiles reflect the process which affects only the Ly $\alpha$  line, mostly the resonant diffusion in the neutral gas. This will allow us to pin down to what extent the structure of the ISM is influencing the profile of the Ly $\alpha$  line.

We present the optical observations in Sect. 2. In Sect. 3 we discuss the shape of the H $\alpha$  and Ly $\alpha$  profiles. The stellar population and its evolutionary state is analyzed in Sect. 4. Finally, we discuss the results in Sect. 5.

## 2. Observations and data reduction

Observations were made using the ISIS double arm spectrometer at the 4.2 m William Herschel Telescope in La Palma on February 27, 1995. A long slit, 1.5 arcsec wide, was positioned over the central part of Haro 2 (RA=10 h 29 m 22 s, DEC=54° 39' 29'') with a position angle of 45°. The spatial resolution was 0.35 arcsec/pix. Exposures of 1800 s were performed in the spectral ranges 3630-5150 Å in the blue, and 6410-6810 Å in the red, with respective spectral dispersions of 1.54 Å/pix and 0.41 Å/pix. The reduction of the images were made using the standard procedures of IRAF. After wavelength calibration we have further corrected for a slight systematic offset (1 pixel) in the direction of dispersion between the line positions of the red and the blue spectra. This could be due to a small mechanical flexure of the arms of ISIS during the observations.

The seeing was unfortunately very poor during these observations, giving a FWHM for stellar images around 5''.5. We have compared this data with some other observations of Haro 2 obtained in March 1995 with the HEX-AFLEX multifiber device in La Palma (in collaboration with S. Arribas and E. Mediavilla), in good seeing conditions (around 1'') to estimate to which extent the bad seeing had degraded the spatial resolution of our spectroscopic observations. We conclude that the effect of the seeing is mostly a “smoothing” of the spatial variations. We have analyzed H $\alpha$  at every pixel along the slit (steps of 0''.35) using bins of 1''.75 in order to study the general trend in the spatial behaviour of its FWHM and to construct the rotation curve for Haro 2.

## 3. Lines profiles

We have first measured the positions and widths of all the emission lines for 3 slit positions, respectively at the center (CE), defined as the position of maximum brightness of the line emission, at 7'' from the center in the north-east direction (NE) and at 7'' from the center in the south-west direction (SW). The results are shown in Table 1.

Since the FWHM of the calibration lines is 1 Å in the red (3 times less than the H $\alpha$  FWHM), the H $\alpha$  profile is well resolved. We have computed a deconvolved  $\sigma = \frac{FWHM}{2\sqrt{2\ln(2)}}$  parameter for H $\alpha$ , which is respectively 55, 51, 55 km/s (+/- 10 km/s) at the 3 positions given above. We note that this is larger than the 30 km/s predicted from the relation of Terlevich & Melnick (1981) between the line absolute intensity and width, assuming  $\log(F(H\beta))=40.62$  (Mas-Hesse & Kunth 1997, in prep.) for Haro 2.

**Table 1.** Haro 2 line measurement

Line	Position	$\lambda_{obs}$	$\lambda_{lab}$	$\sigma_{obs}$	$\sigma_{dec}$	$V_{rec}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)
NII $\lambda$ 6548	NE	6579.6	6583.4	66.3	63.41	1450
NII	CE	6579.4	6583.4	51.4	47.56	1433
NII	SW	6578.9	6583.4	63.7	60.7	1413
H $\alpha$	NE	6594.5	6562.9	58.5	55.2	1444
H $\alpha$	CE	6594.1	6562.9	54.4	50.8	1428
H $\alpha$	SW	6593.9	6562.9	59.2	55.9	1418
NIII $\lambda$ 6584	NE	6615.3	6583.4	55.8	52.4	1454
NII	CE	6614.9	6583.4	53.3	49.7	1436
NII	SW	6614.6	6583.4	58.7	55.4	1425
SII $\lambda$ 6717	NE	6749.1	6716.4	56.7	53.5	1461
SII	CE	6748.7	6716.4	55.4	52.1	1442
SII	SW	6748.1	6716.4	55.5	52.1	1416
SIII $\lambda$ 6731	NE	6763.6	6730.8	55.4	52.1	1464
SII	CE	6763.1	6730.8	54.9	51.5	1443
SII	SW	6762.7	6730.8	55.3	51.9	1421

*Columns:*

- (1) : Line identification.
- (2) : SW, CE and NE respectively for the SW, central and NE regions (integrated over 7").
- (3) : Observed wavelength in Å.
- (4) : Rest wavelength in Å.
- (5) : Measured  $\sigma$  parameter in km/s.
- (6) : The  $\sigma$  parameter deconvolved from the instrumental profile (1 Å resolution), in km/s.
- (7) : Recession velocity in km/s.

Moreover, the wings of the H $\alpha$  line (and also, the wings of the nitrogen and sulfur lines) are broader than a simple gaussian profile (Fig. 1) and show a slight asymmetry. The flux excess in the red and blue wings (as compared to a gaussian) is respectively around 2.2 % and 3.8 % of the total H $\alpha$  line flux.

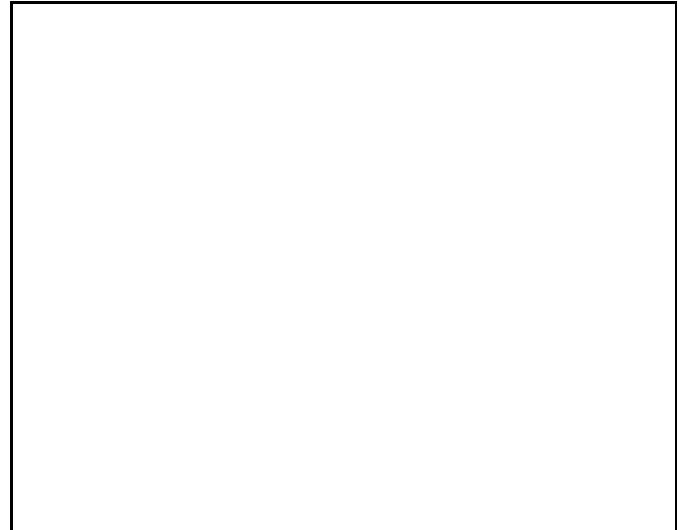
To assess the significance of this observed asymmetry in H $\alpha$ , we have compared it with the instrumental profile, by convolving a calibration line of the same intensity with a gaussian of FWHM=2.7 Å. The comparison of both profiles shows that the wings of H $\alpha$  cannot be purely instrumental but are intrinsic to the galaxy, confirming that the red wing is about 35% less intense than the blue wing (Fig. 1). We have also measured the position and the FWHM of the H $\alpha$  line along the slit with an accuracy respectively better than 5 km/s for the position and 0.3 Å for the FWHM. We have noticed that the FWHM of H $\alpha$  increases from the central region to the external ones (Fig. 2) and that simultaneously the relative contribution of the broad wings to the total flux increases.

The rotation curve we have obtained shows two discontinuities at around 13" from the center in both directions, as shown in Fig. 3. The velocity of the gas at these two



**Fig. 1.** H $\alpha$  emission integrated over the central 7" (CE) of Haro 2. The unsmeared observed H $\alpha$  emission profile is in solid line while the gaussian fit is given in dashed lines. The excess intensity in the wings amounts to 2.2 % and 3.8 % of the total H $\alpha$  line flux in the red and in the blue respectively.

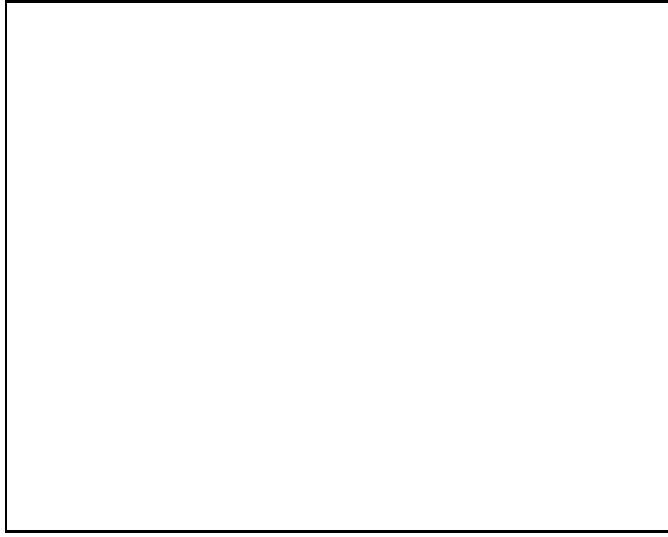
discontinuities is similar to the recession velocity of the nuclear region.



**Fig. 2.** FWHM of the H $\alpha$  line versus position in Haro 2. The represented error bars in the measurement of the FWHM amount to 0.3 Å

We have finally compared the profiles of the H $\alpha$  and the HST Ly $\alpha$  (Lequeux et al. 1995) emission lines, according to the following approach:

1. The spectra of the central part of Haro 2 have been extracted over 6 pixels (2"), corresponding to the same



**Fig. 3.** Rotation curve obtained from H $\alpha$  in Haro 2. The error bars have been computed assuming an average uncertainty of 5 km/s on the position of H $\alpha$

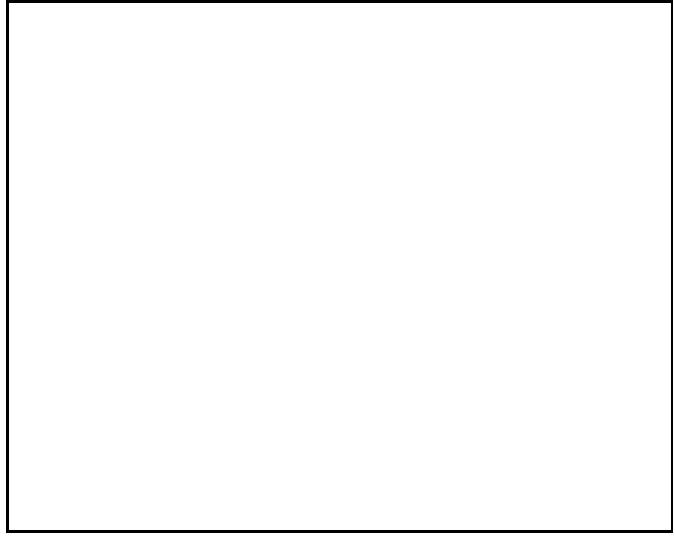
aperture than the HST observations (Lequeux et al. 1995).

2. We have blueshifted H $\alpha$  to the wavelength of the observed Ly $\alpha$ , conserving its flux.
3. The H $\alpha$  emission line has been multiplied by 11.4, the theoretical Ly $\alpha$ /H $\alpha$  ratio assuming case A in the recombination theory and an electronic temperature of 10000 K (Osterbrock, 1989).
4. The Ly $\alpha$ /H $\alpha$  has been corrected from reddening effects, assuming a Small Magellanic Cloud extinction law with E(B-V)=0.2. This has decreased the ratio to about 5.
5. The transfer function for Ly $\alpha$  through the interstellar medium has been obtained by using Xvoigt (see Sect. 4) .
6. Finally, the blueshifted H $\alpha$  profile has been convolved with the transfer function for Ly $\alpha$  in order to obtain the intrinsic Ly $\alpha$  profile one would expect if both lines were originated in the same region under similar physical conditions.

Comparing the observed Ly $\alpha$  profile with the predicted one (Fig. 4) one can see that the observed Ly $\alpha$  line appears to be, in all cases, much broader than expected. This implies the existence of additional sources of Ly $\alpha$  photons at large velocities.

#### 4. Analysis of the stellar population

Several authors (Larson 1986, Augarde & Lequeux 1985, Rieke et al. 1993) have suggested that, in active star formation regions, the production of low mass stars should be hampered by the destruction of the molecular clouds, in which low mass stars are formed, by the energy re-



**Fig. 4.** Comparison between the Ly $\alpha$  profile expected from H $\alpha$  (ratios 5 in dashed lines and 11.4, in dotted lines) and that observed with HST (solid line). The observed Ly $\alpha$  emission is always broader than the one expected from H $\alpha$

leased by massive stars and supernovae. This could result in a truncation of the Initial Mass Function (IMF) at the low mass star end. Such a truncation can have observable effects on the equivalent widths (EW) of the Balmer absorption lines (Olofsson 1995). As shown by various authors (e.g Cananzi et al. 1993), the equivalent widths of the stellar Balmer lines is a sensitive indicator of the IMF in very young populations. We have thus measured the absorption lines of the Balmer series in Haro 2, using two different methods. First, we have used IRAF to fit two gaussians, one for the emission line, one for the absorption line and second, we have used the program Xvoigt<sup>1</sup> which allows to adjust “by eye” a Voigtian absorption profile on the wings of the Balmer lines. This program computes the observed absorption profile of different atomic lines produced by a cloud for which we can fix the density, the velocity dispersion and the redshift. Both methods lead to the same values, with differences smaller than 0.5 Å. We adopted the values measured with Xvoigt. The results are summarized in Table 2.

Fanelli et al. (1988) have analyzed the UV spectrum of Haro 2 using optimized, non-evolutionary, stellar synthesis techniques. These authors derived a strongly discontinuous luminosity function for this galaxy, concluding that the present burst of star formation has been preceded by at least two bursts, the most recent of which ended not more than 20 Myr ago. Mas-Hesse & Kunth (1997 in prep.) have also analyzed this galaxy applying evolutionary synthesis techniques. They obtain an age of 4 – 5 Myr for the present burst, with best fits obtained for a rather steep

<sup>1</sup> Xvoigt, Copyright 1994, David Mar

**Table 2.** Measurement of the Balmer absorption lines.

Line	Position	EW
	(1)	(2)
H $\epsilon$	3970.1	4.6 $\pm$ 0.5
H $\delta$	4101.7	4.7 $\pm$ 0.5
H $\gamma$	4340.4	4.1 $\pm$ 1.0

*Columns:*

(1) : Rest wavelength in Å.

(2) : EW in Å measured with Xvoigt.

( $\alpha \geq 3.0$ ) IMF (defined as  $dN/dm = \phi(m) \propto m^{-\alpha}$ ) and a nearly instantaneous star-formation episode. The models of Mas-Hesse & Kunth (1997, in prep.), based on the fit of the UV continuum, clearly underestimate the optical continuum. The stars formed in the present burst, the only one to which the UV range is sensitive, account indeed for not more than 60% of the total optical emission, indicating that an important fraction of the stellar population was formed prior to the present burst. Krüger et al. (1995) obtain indeed also a good fit to the optical and near infrared continuum by assuming that a 5 Myr long starburst has taken place on a galaxy having formed stars continuously, but at a lower rate, during the last 15 Gyr. Finally, Loose & Thuan (1986) detected a change in stellar populations from O to F6 main sequence stars as radius increases, concluding that Haro 2 is an elliptical galaxy with very active star formation activity in its center.

We have compared the observed Balmer absorption line equivalent widths with the predictions made by Olofsson (1995), based on evolutionary models computed assuming various truncations of the IMF. To be consistent with previous results, we have assumed a two-burst model with IMF slope  $\alpha = 2.5$ . The relative strength of each burst was chosen to reproduce the total optical emission. No unique solution can be derived from the calculation but we have found that in any case the observed equivalent widths exclude models in which the IMF is truncated below  $10 M_{\odot}$ . Therefore, if the onset of a starburst inhibits the formation of low mass stars, this result shows that the process should be effective only at masses clearly below  $10 M_{\odot}$ , if any.

According to the results by Mas-Hesse & Kunth (1997, in prep.), the mass transformed into stars in the mass interval between 2 and  $120 M_{\odot}$  is rather high (more than  $10^6 M_{\odot}$ ), and the burst is in a quite late phase (at around 4.5 Myr), so that the amount of kinetic energy released by such an episode (stellar winds, supernovae explosions) is large enough for having disrupted the interstellar medium, as we will discuss below.

## 5. Discussion

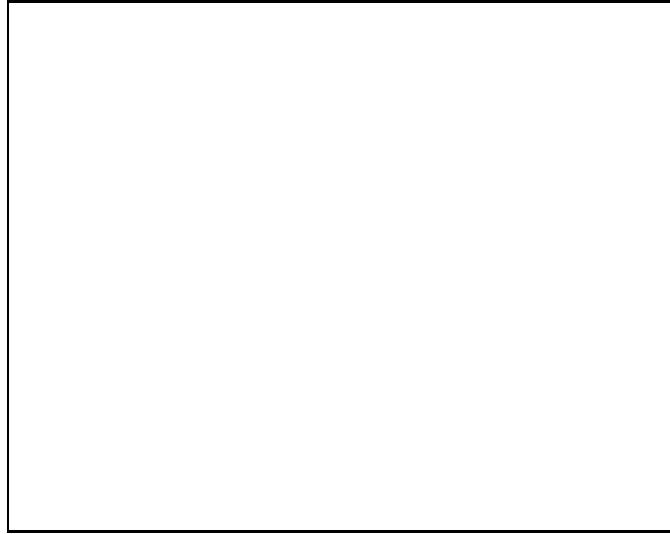
The excess in the velocity dispersion measured in the central region of Haro 2 with respect to the correlation from Terlevich & Melnick (1981) can be explained by the combination of rotation and seeing effects. The rotation curve shows a variation in the position of H $\alpha$  of 0.5 Å (20 km/s) per 5-6''. Since the seeing was of this order, we would expect an increase in the observed FWHM of the lines by about 20 km/s. It seems therefore that the correlation given by these authors should flatten for large galaxies in which the rotation introduces a measurable effect, while it remains valid for smaller HII galaxies with no significant rotation.

Lequeux et al. (1995) have shown evidences for the existence of an expanding shell at 200 km/s in Haro 2. We will discuss now how our optical observations can be interpreted in this scenario, and will derive a simple geometrical model for Haro 2. As we have shown above, the H $\alpha$  emission profile shows two broadened wings. By assuming that the total H $\alpha$  line is due to the emission from a central HII region and to the additional emission from a partially ionized shell expanding at 200 km/s, we have attempted to fit the H $\alpha$  profile by the sum of three gaussians with velocities of 0, +200, and -200 km/s with respect to the center of the H $\alpha$  line (Fig. 5). Our fit can reproduce the broadening of the line profile, indicating that the wings are consistent indeed with the emission coming from an expanding shell. The total contribution of this shell to the total H $\alpha$  luminosity would be close to 7%. The residuals that are evident from the fit shown in Fig. 5 would be reduced by considering a more realistic convolution of gaussians at velocities around  $\pm 200$  km/s, as expected in an expanding shell, instead of single velocity values.

Finally, the broadening of the wings is asymmetric. This can be explained if the broadening is indeed due to an expanding shell. Photons coming from the receding part of the shell are likely to be absorbed by dust within the HII region and the front part of the shell while those emitted by the foreground part of the shell can escape directly.

The H $\alpha$  line intensity strongly decreases as we go away from the center. The intensity scale between the center and a distance of 10 arcsec or more is roughly a factor of 10. Over this distance the rotation curve has been measured.

At about 13'' from the center the velocity decreases to reach the value measured in the central region, before increasing again. This suggests that we are detecting emission from gas whose motion does not follow the galaxy rotation and appears at the same velocity -the systemic velocity- than the central region. We suggest that this gas is precisely the ionized part of the expanding shell ejected by the central region. Since this effect starts to appear at 3.5'' of the central region, we conclude that the radius of the central HII region is around this value, which is consistent with the estimation of 3'' by Lequeux et al.



**Fig. 5.** Line fitting to the observed H $\alpha$  line in the central (CE) region. The three component gaussian fit is given by the dashed line while the observed H $\alpha$  emission is represented by the solid line. The three fitted gaussians are at 0, +200 and -200 km/s with respect to the center of the line. The intensity contribution of the two components at +200 km/s and -200 km/s is around 7% of the central line.

(1995). Therefore, at larger distances the emission starts to be dominated by the shell. We have measured the contribution to the total H $\alpha$  luminosity of the two regions at around 10''. This contribution is found to be around 6-7 %, which is consistent with our previous estimation of the contribution of the shell to H $\alpha$ . Moreover we argue that locations where the gas emission appears at the same velocity than that of the nucleus correspond to the “border” of the emission shell. This allows us to limit the radius of the ionized shell to 13'' or 1.23 kpc (Ho=75 km/s/Mpc). Marlowe et al. (1995) have found bubbles with sizes of the same order. Using this result and the expanding velocity of 200 km/s we can evaluate the characteristic dynamical timescale of the shell to be 5-6 Myr. This timescale corresponds to the start of the present nuclear starburst, estimated at 4-5 Myr by Mas-Hesse & Kunth (1997, in prep.).

We can estimate the kinetic energy of the neutral expanding gas that is pushed out by the shell by

$$E_k(\text{HI}) = \frac{1}{2} 4 \pi r^2 N(\text{HI}) m_p v^2,$$

where  $r$  is the radius of the shell,  $N(\text{HI})$  the column density of the neutral gas,  $m_p$  the mass of the proton and  $v$  the mean expansion velocity. Lequeux et al. (1995) have evaluated the column density of the neutral gas expanding with the shell to be  $N(\text{HI}) = 7 \cdot 10^{19} \text{ cm}^{-2}$  on the line of sight. Adopting this value we find  $E_k(\text{HI}) = 4.53 \cdot 10^{54} \text{ ergs}$  and a mass for the expanding gas of  $6 \cdot 10^6 M_\odot$ . We have applied the relation of Marlowe et al. (1995) by using the Castor et al. (1975) model which gives the evolution of the

radius and the expansion velocity of a bubble expanding adiabatically:

$$r_{\text{bubble}} = 1.0 \left( \frac{dE}{dt} \right)_{41}^{1/5} n_0^{-1/5} t_7^{3/5} \text{ kpc} \quad (1)$$

$$v_{\text{bubble}} = 62 \left( \frac{dE}{dt} \right)_{41}^{1/5} n_0^{-1/5} t_7^{-2/5} \text{ km s}^{-1} \quad (2)$$

where  $\left( \frac{dE}{dt} \right)_{41}$  is the kinetic energy injection rate in units of  $10^{41} \text{ erg s}^{-1}$ ,  $n_0$  is the number density in the medium, and  $t_7$  is the time since the expansion began in units of  $10^7 \text{ yr}$ . The density of the medium is not known, and Marlowe et al. (1995) adopt  $n_0 = 0.3$ . The kinetic energy injection rate for Haro 2 is  $4.34 \cdot 10^{41} \text{ erg s}^{-1}$  at 6 Myr (Cervino et al. 1997, in prep.). Using this value and adopting, rather arbitrarily,  $n_0 = 0.3 \text{ cm}^{-3}$ , we have evaluated the size and speed of the bubble. We find  $r_{\text{bubble}} = 1.26 \text{ kpc}$  and  $v_{\text{bubble}} = 130 \text{ km s}^{-1}$  for an age of 6 Myr. Taking into account the inherent uncertainties, this is consistent with our estimations for the size and the velocity. The discrepancies with the measured values can be partially explained by the expected asymmetry of the shell. No neutral gas at the systemic velocity has been detected with HST in front of the central cluster, although we know from radio observations that there are significant amounts of neutral hydrogen surrounding Haro 2. We expect therefore that in the line of sight we are detecting outflowing gas which is reaching the limits of the cloud. On the other hand, the gas column density should be much larger in the direction perpendicular to the line of sight, where we have measured the size of the shell. We have therefore used the precedent relations to constrain the density in both directions, using the computed kinetic energy and other observed parameters for a 6 Myr old shell. In formula (1), using the radius of 1.26 kpc, we have computed for the direction perpendicular to the line of sight, a value of  $n_0 = 0.33 \text{ cm}^{-3}$  as an upper limit. In formula (2), the velocity of 200 km/s measured on the line of sight with the HST gives a value of  $n_0 = 0.03 \text{ cm}^{-3}$  as a lower limit in this direction.

We have mentioned that the FWHM of the H $\alpha$  line increases with the distance to the center. This means that as we are leaving the central region (along the slit), the contribution of the central HII region to H $\alpha$  decreases, but not the one of the shell. This results in an increasing contribution of the shell to H $\alpha$  and then to a broadening of this line due to the shell. The double peaked profile expected for the expanding shell alone is most probably smoothed by the poor seeing. New observations around H $\alpha$  with high spatial and spectral resolution under good seeing conditions may allow us to see this effect.

Comparison between H $\alpha$  and Ly $\alpha$  has revealed the existence of additional sources of Ly $\alpha$  photons at high velocity. If the receding ionized shell (or any other ionized region) were responsible for this emission, it would also produce H $\alpha$  photons with the same kinematical properties and showing therefore similar profiles. We interpret this extra emission as photons backscattered by resonant diffusion on the receding neutral part of shell, as suggested by Lequeux et al. (1995). Note that these backscattered

photons, diffused at +200 km/s, would not be absorbed at all by the medium in the line of sight, which is at very different velocities.

From the results we have discussed up to now, we can sketch a simple geometrical scenario for Haro 2 inspired on several theoretical frameworks (Castor et al. 1975; Weaver et al. 1977; Martin 1996; Tenorio-Tagle 1996): A central starburst ionized region, at the systemic velocity, contains most of the recent stars. Since the HST spectra show the presence of OI and SiIII absorptions at -200 km/s, we infer the existence of a partially ionized expanding shell at this velocity, whose emission should contribute to the observed wings of H $\alpha$ . The inner part of the ionized region could be constituted by the ejected materials from the central starburst while the outer part would be formed by the ionized interstellar medium. The inner gas is photoionized and perhaps partially ionized by shock-waves propagating from the interfaces between the ejected and the interstellar media (if the ionization produced by shocks is important, we should see some typical emission lines, like [OI]6300Å, which is not the case. Nevertheless, these lines are expected to be weak and since the contribution of the shell is very small they would remain below our level of detection). Since Ly $\alpha$  emission from the central region at 0 km/s is observed, there cannot be static HI gas on the line of sight. A “champagne flow” outcoming from the internal regions could be starting to form here. On the other hand, we speculate that larger amounts of static neutral gas could be present in the direction perpendicular to the line of sight, being responsible for the bulk of HI radio emission detected at the systemic velocity. The neutral outer layers of the expanding shell would be responsible for the absorption of Ly $\alpha$  photons detected with HST. On the other hand, diffusion at the receding sections of the shell would backscatter Ly $\alpha$  photons which would explain the excess of emission detected in the red wing of this line.

This scenario exemplifies once again that the detectability of Ly $\alpha$  emission in starburst galaxies requires the combination of several effects, as concluded by Kunth et al. (1996):

- The presence of an ionized medium producing Ly $\alpha$  photons.
- The absence of neutral gas at the velocity of the Ly $\alpha$  emission source in the line of sight, i.e., the presence of large gas flows in the line of sight, not hidden by more external static, neutral clouds.

Therefore other effects suggested in the past, like dust abundance, metallicity, evolutionary state of the cluster, etc..., do not play the only role in the process. This explains why the very metal deficient and dust-free galaxy IZw 18 shows nevertheless no Ly $\alpha$  in emission. IZw 18 is surrounded indeed by large amounts of neutral HI gas at low velocity. Ly $\alpha$  photons diffusion by neutral hydrogen would be produced independently on the presence or absence of dust grains. If dust particles are abundant, they

would end absorbing the major part of the diffused photons. On the other hand, if dust effects are not significant, a glow of leaking Ly $\alpha$  photons should be detected around the whole neutral HI cloud surrounding starburst galaxies. Maybe efficient detectors in the future will be able to detect this Ly $\alpha$  glow.

## 6. Conclusion

We summarize the main results of this work:

- We have confirmed the existence of a partially ionized shell expanding at 200 km/s in Haro2. The contribution of this shell to the total H $\alpha$  luminosity is around 7%.
- The size of the shell has been evaluated to be 1.23 kpc and its age to 6 Myr, being apparently related to the last starburst event.
- The shell is not affected by the rotation of the galaxy.
- We confirm the Lequeux et al. (1995) hypothesis that backscattering is responsible for the broadening of the red wing of the Ly $\alpha$  emission.
- This starburst event probably has an IMF including stellar masses lower than 10 M $\odot$ .

We have shown that long-slit high resolution spectroscopy around H $\alpha$  combined with Ly $\alpha$  spectroscopy is a powerful tool to study the geometry and kinematic of the ISM. These observations of Haro 2 show that Ly $\alpha$  photons can escape because of a particular structure and kinematic of the ISM, as suggested by Kunth et al. (1996) and Giavalisco et al. (1996). Both factors strongly affect the profile of the Ly $\alpha$  emission line and become major drivers for its detectability.

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